Numerical Studies of Acoustic Propagation in Shallow Water

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LONG-TERM GOAL

To develop “exact” numerical methods that can be used to study the propagation of acoustic energy in shallow water. Exact in this contexts means that the methods place no restrictions on the underlying physics of the environment.

OBJECTIVES

To develop new, and enhance existing, numerical methods; to establish the accuracy, robustness, flexibility, and tractability of these methods; and to apply these methods to meaningful practical problems.

APPROACH

We have focused our attention on the development and use of the finite-difference time-domain (FDTD) method. This time-domain technique, which is flexible, robust, and simple to implement, has previously been used by the electromagnetics community to solve a wide range of problems. However, the FDTD method has not been widely used by the acoustics community and its ability to accurately solve many of the problems related to propagation in a shallow water environment is the subject of continuing research.

WORK COMPLETED

Fundamental aspects of the discretized FDTD world were studied and quantified; FDTD algorithms were developed; the corresponding computer programs were written; and information was disseminated via journal publications, conference presentations, and the Web.

RESULTS

Numerical methods, such as the FDTD method, model a finite physical space. In order to simulate the behavior of an unbounded space, the computational domain must be terminated with a suitable “absorbing boundary condition” (ABC). We demonstrated the application of a new ABC to 3D acoustics problems [JASA, **104**(2):686--693, 1998]. This ABC is attractive in that, not only does it provide much greater accuracy than older ABC's, it is much simpler to implement than other high-performance grid-termination schemes (such as the perfectly matched layer) [*IEEE Microwave and*

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Guided Wave Let., **8**(1):55--57, 1998]. The standard FDTD scheme approximates hard and pressure-release boundaries (such as pertain at an impenetrable bottom or at the air-sea interface) using a staircase representation. We presented a simple technique to improve the representation of pressure release boundaries in 3D acoustic simulations [JASA, **104**(6):3219--3226, 1998]. We performed a rigorous analytic analysis of two locally conformal schemes designed to alleviate staircasing errors [IEEE AP-S International Symposium and URSI Radio Science Meeting, 4:1816--1819, 1998, and a paper to appear in *IEEE Trans. Microwave Theory Techniques*, Jan. 1999]. Along the same lines, we performed careful FDTD simulations of propagation in wedge structures to establish guidelines for acceptable cell sizes using staircased boundaries [*IEEE Trans. Antennas.Propagat.*, **45**(12):1830--1838, 1997].

We developed a new technique for introducing fields into FDTD computational grids. This technique permits the source of fields to be “transparent” so that the source itself does not interfere with the propagation of fields. Publications appeared which described both the behavior of individual transparent sources [JASA, **103**(1):3219--3226, 1998] and arrays of transparent sources (or transparent screens) [*IEEE Trans.Antennas Propagat.*, **46**(8):1159--1168, 1998].

We firmly established the ability of the FDTD method to model accurately the scattering from randomly rough pressure-release surfaces. This was previously done for infinite surfaces using a Monte Carlo technique and recently for a single “benchmark” rough surface [JASA, **102**(6):3394--3400, 1997]. Additionally, we have made progress in establishing the use of the FDTD method for elastic rough surfaces [*Proc. 135th Meeting Acoust. Soc. Am.*, **4**:3025--3026, 1998].

Furthermore, our investigations have led to a new understanding of the way in which waves propagate in the discretized world of the FDTD grid. We have shown that, counter to previous thought, the FDTD grid supports, and indeed requires, waves that propagate faster than their counterparts in the physical world. With this new understanding, it is possible to derive expressions for the fields that will exist in a (uniform) grid without actually having to perform a FDTD simulation [submitted to *IEEE Microwave and Guided Wave Let.*]. This may prove to be significant in many aspects of numerical modeling including the way in which energy is introduced into the grid and the way in which grids are terminated. We have also discovered another fundamental way in which the discretized world differs from the physical world and have shown how simulations which included lumped elements should be modified to account for this difference [to appear in *IEEE Trans. Microwave Theory Techniques*, Dec. 1998].

(The full citations for the work described above, as well as for additional publications acknowledging ONR funding, are given below.)

IMPACT/APPLICATIONS

Accurate and flexible numeric methods give one the ability to conduct any number of experiments without having to resort to actual field experiments, i.e., the experiment is conducted in the computer. Although numerical methods will never supplant field experiments, numerical methods (when used within their “region of validity”) do provide an extremely cost-effective means of conducting controlled experiments. Our work will enable more accurate and more efficient numerical solutions to a wide range of problems in acoustics, electromagnetics, and continuum mechanics.

TRANSITIONS

Much of the knowledge we have gained has been disseminated via publications and conference publications. Additional material is available via the Web (please refer to Web site given in the header).

RELATED PROJECTS

This work is related to research being conducted in both high-frequency acoustics and long-range propagation. Numerical models, such as the FDTD method, can be used to predict the fields scattered from small objects under short-wavelength insonification or the propagation of long-wavelength signals over limited regions of the ocean. Additionally, this work is related to the work being conducted by several other ONR-sponsored researchers including Shira Broschat, Eric Thorsos, and Philip Marston.

PUBLICATIONS

- J. B. Schneider and K. L. Shlager, "FDTD Simulations of TEM Horns and the Implications for Staircased Representations," *IEEE Trans. Antennas Propagat.*, vol. 45, no. 12, pp. 1830-1838, 1997.

- F D. Hastings, J. B. Schneider, and S. L. Broschat, "A Finite-Difference Time-Domain Solution to Scattering from a Rough Pressure-Release Surface," *J. Acoust. Soc.* Am., vol. 102, no. 6, pp. 3394-3400,1997.

- J. B. Schneider, C. L. Wagner, and S. L. Broschat, "Implementation of Transparent Sources Embedded in Acoustic Finite-Difference Time-Domain Grids," *J. Acoust. Soc.* Am., vol. 103, no. 1, pp.136-142,1998.

- T. J. Snyder, J. N. Chung, and J. B. Schneider, "Competing Effects of Dielectrophoresis and Buoyancy on Nucleate Boiling and an Analogy with Variable Gravity Boiling Results@" *Trans. ASME:* ***J*** Heat Transfer, vol. 129, pp. 371-379, May 1998.

- M. Ramahi and J. B. Schneider, "Comparative Study of the PML and C-COM Mesh-Truncation

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- J. B. Schneider, C. L. Wagner, and 0. M. Ramahi, "Implementation of Transparent Sources in DTD Simulations," *IEEE Trans. Antennas Propagat.*, vol. 46, no. 8, pp. 1 1 59-1168, 1998.

- C. J. Railton and J. B. Schneider, "An Analytical and Numerical Analysis of Several LocallyConformal FDTD Schemes," accepted for publication in *IEEE Trans. Microwave Theory and Techniques.*

- J. B. Schneider, C. L. Wagner, and R. **J.** Kruhlak, “Simple Conformal Methods for FDTD Modeling of Pressure-Release Surfaces,” *J. Acoust. Soc.* Am., vol. 104, no. 6, pp. 3219-3226, 1998.

- C. L. Wagner and **J.** B. Schneider, “Divergent Fields, Charge, and Capacitance in FDTD Simulations,” accepted for publication in *IEEE Trans. Microwave Theory and Techniques.*

- F. D. Hastings, J. B. Schneider, S. L. Broschat, and E. 1. Thorsos, “A Comparison of the FiniteDifference Time-Domain and Integral Equation Methods for Scattering from Shallow Water Sediments,” abstract: *J. Acoust. Soc. Am.*, vol. 103, no. 5, pt. 2, pp. 3095; proc. paper: *Proc. 135th Meeting Acoust. Soc.* Am., vol. 4, pp. 3025-3026, Seattle, WA, Jun. 1998.

- J. B. Schneider and C. L. Wagner, “Analytic Analysis of the CP-FDTD and C-FDTD Methods for Offset Planar Boundaries,” IEEE AP-S International Symposium and URSI Radio Science Meeting, vol. 4, pp. 1816-1819, Atlanta, GA, Jun. 1998.